Reflective Light Modulation by Cephalopods in Shallow Nearshore Habitats

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LONG-TERM GOALS

The central question is: what are the optical principles upon which crypsis is achieved by opaque organisms in shallow, nearshore marine habitats?

OBJECTIVES

Camouflage mechanisms are not well known despite the general misconception that they are. Moreover, quantification of camouflage (especially of opaque organisms) is particularly wanting. We have three objectives: (1) Acquire imagery (camouflaged animals and their backgrounds) and corresponding irradiance data from coral reef and temperate rock reef environments. (2) Perform image analyses to quantify the degree of crypsis. (3) Construct a comparative digital photographic library of shallow-water marine animals in the camouflage categories of Uniform, Mottle and Disruptive. The central focus is on octopus, cuttlefish and squid because they have the most diverse and changeable camouflage patterns known in biology. Fish and insects are studied comparatively.

APPROACH

High-resolution digital still images (Canon EOS 1Ds, Mark II camera) are acquired under natural marine conditions. No flash is used to avoid making artificial shadows from the flash light. A computer-controlled spectrometer (adapted for underwater use) takes downwelling and sidewelling irradiance data at the exact time of photography; then the animal reflectance data are recorded with the spectrometer (in both gross and fine detail on the animal's body) so that color- and contrast-matching can be quantified in the digital images. HDTV video is used to follow foraging cephalopods and fish to document (a) speed of body patterning changes and (b) the range of microhabitats that they encounter and the pattern they choose to camouflage themselves in each microhabitat.

WORK COMPLETED

Field work continued at a vigorous pace during 2008. RTH completed 5 field trips (total of 56 SCUBA dives) and acquired 2,384 high-resolution digital still images of cephalopods and fishes. Briefly, the breakdown is as follows. (1) Izmir, Turkey, March 2008, to photograph the common European cuttlefish *Sepia officinalis* in natural habitats. (2) Florida Keys, Aquarius habitat, May 2008. Images and HDTV video of large groupers as well as four other reef fishes changing patterns for camouflage. (3) Heron Island, Great Barrier Reef, Australia, June 2008. Still images and HDTV video of fish camouflage change, including medium-sized groupers. (4) Whyalla, S. Australia, June 2008, to study the giant Australian cuttlefish *Sepia apama*. Still images and HDTV of camouflage change both

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day and night (see RELATED PROJECTS below on National Geographic Society grant to augment this effort). (5) Vigo, Spain, July 2008, to photograph the common European cuttlefish *Sepia officinalis* in natural habitats to complement the Turkey trip; each has different ecotypes.

Image analyses this year centered on development of a suite of methods to be used as evaluation tools for camouflage effectiveness. The variogram approach has been dropped as a major focus because after months of effort its utility is questionable. This suite of methods (nearly 20 total) is divided into 3 basic approaches. The first is texture analyses, which comprise granularity statistics, 1st order intensity histogram statistics, 2nd order structure-based intensity statistics, and structure-based variogram. The second is feature detectors, which include edge detectors, harris corner detectors and morphological operators. The third is gestalt psychology, which applies the principles of human visual perception through figure/ground segregation and psychophysics experiments.

Concept development of camouflage visual mechanisms progressed well this year. Perhaps the central focus within the vision science/behavioral ecology community is on how to prove quantitatively and experimentally that disruptive coloration is a separate mechanism from background matching. Our lab has been a major player in this because we specialize in the animal group that is most advanced in adaptive coloration, the cephalopods. We combined our recent lab experiments (not funded on this grant) with recent field observations and images (funded on this ONR grant) to produce a paper (in press; see below) demonstrating support for one of the key attributes hypothesized for disruptive coloration: that contrast on the animal's body pattern can be very high, and will match and even exceed that of the visual surrounds. This is a counterintuitive notion, since most people will assume that high contrast will make an animal more visible, not more camouflaged.

RESULTS

Photography and Videography *in situ*. One key question in camouflage effectiveness is how well certain patterns scale up; that is, does a certain pattern seen in a small animal work on a large animal? If so, on what type of visual background will it work? To that end, we have been seeking a location where we can find *large groupers* and see if they (i) can change their camouflage patterns, and (ii) use the same range of camouflage patterns as small groupers. As reported last year, we have a good photographic base on Nassau groupers showing that they use the 3 basic camouflage pattern types that we discovered in cephalopods: Uniform, Mottle and Disruptive (UMD).

Figure 1 shows two Goliath groupers, *Epinephelus itajara*, next to NOAA's Aquarius underwater manned habitat off Key Large, FL. The larger grouper is ca. 130lbs. We dived around this habitat for one week in May 2008 and obtained several hundred photographs, but none against natural backgrounds. However, this figure shows an important feature of grouper camouflage: they can control the contrast of their skin patterns, and our video shows that they can change contrast and pattern in about 3-5 seconds (and perhaps faster). We found that they show UMD patterns similar in construction to UMD in small Nassau groupers. Thus, large fish are also using UMD for camouflage, and the basic makeup of the pattern (in this case, vertically arranged disruptive bands) is similar.

Disruptive camouflage measurements of high contrast. Figure 2 provides measurements of contrast in disruptive camouflage patterns in cuttlefish, *Sepia officinalis*. The top two images show a lab image in which the so-called "white square" skin component of the cuttlefish is higher in contrast than 20 other discrete blobs in the visual background. The 4 remaining photographs are from this year's field

Figure 1. Two large Goliath groupers at 22m depth showing a high-contrast Disruptive camouflage pattern (lower fish) and a lower-contrast Mottle pattern (upper fish). Both fish changed pattern and contrast readily and swiftly.

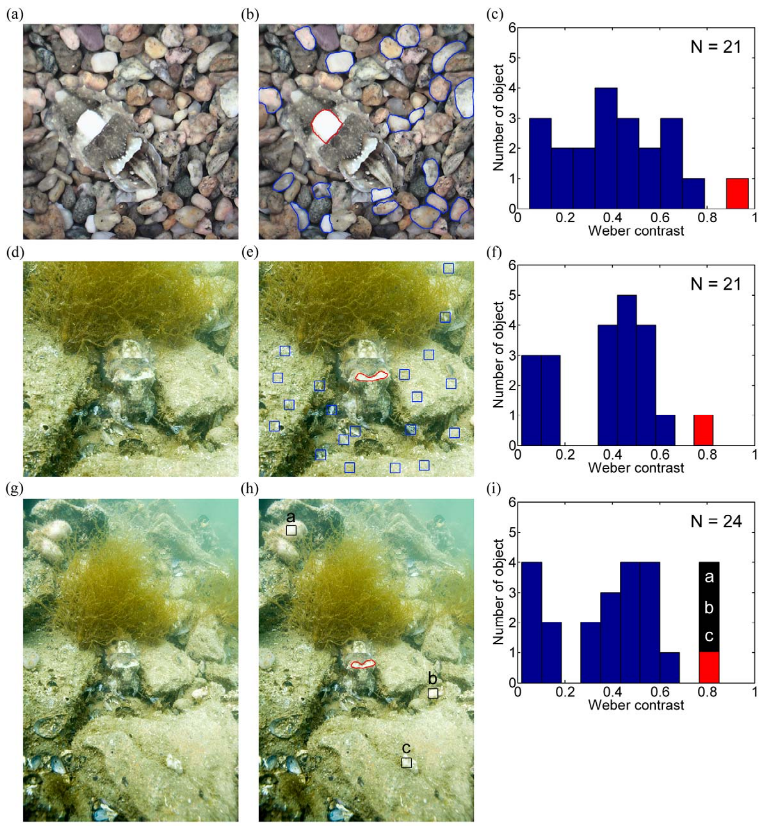

Figure 2. Cuttlefish in a disruptive camouflage pattern in the lab (a,b) showing higher body pattern contrast than the visual background (c). Cuttlefish in nature (d,e) also shows higher contrast than the immediate surrounds (f-red bar) but when viewed from afar (g,h) they equal surrounding contrast (compare red bar with blobs a,b,c in image h).

work in Turkey. This animal, when viewed closeup (images a,b) has higher contrast on its "white head bar" than 20 samples of the immediate surrounds, suggesting a disruptive visual effect. When viewed in wider scope (as in distance or peripheral vision by a predator; images d,e), the cuttlefish white head bar is comparable in contrast to other light objects in the visual field, thus becoming a random sample of other light objects. This latter phenomenon is a form of background matching. Thus, a single pattern may be achieving camouflage by a combination of disruptive coloration as well as background matching.

IMPACT/APPLICATIONS

The discovery that large fishes such as Goliath groupers (comparable in size to a human) use Uniform, Mottle and Disruptive patterns provides insight into camouflage mechanisms, because Uniform and Mottle patterns work by background matching, whereas Disruptive works partly by background matching but also by obscuring the recognizable outline or shape of the animal. In short, camouflage in nature uses two primary tricks: it interferes with detection (via background matching) or interferes with recognition (via disruptive coloration) by the predator. Our paper (cited below) suggests that certain camouflage patterns might address both visual camouflage mechanisms simultaneously.

We learned in the S. Australia work (see below on NGS grant) that cuttlefish at night do not produce a very good color match, although other key factors (e.g. overall intensity, contrast, pattern) are very well matched. This supports the idea that marine nocturnal predators are not capable of using color vision, so that night camouflage is an achromatic process, not unlike the terrestrial IR world that the military operates in during night operations.

TRANSITIONS

A few of our original ideas on mechanisms of camouflage are being considered by ARL and DARPA.

RELATED PROJECTS

The PI has two related projects sponsored by military agencies. We continue to benefit from them in terms of developing a suite of methods that can be used for quantifying various aspects of camouflage. This has been immensely helpful in testing novel approaches to quantifying camouflage, a subject that has received only scant attention in any of the scientific fields.

A third related project was conducted in June and July 2008 sponsored by a National Geographic Society Research Grant. The NGS grant was presented as augmentation to this ONR grant, and the objective was to acquire a large sample (i.e. >500) of 3D images of camouflaged cuttlefish both day and night, and to determine whether these animals color match as well at night as they do in the daytime. We used an AUV to conduct surveys at day and night, and we augmented this with a select number of SCUBA dives with hand-held cameras to obtain comparative images. The marine operations were highly successful and we obtained nearly 1000 images of cuttlefish camouflage that will be analyzed in the next year.

PUBLICATIONS

A special volume on Camouflage has been arranged for Philosophical Transactions of the Royal Society. We were invited to submit a paper and it was accepted 20 Sep 2008.

Hanlon RT, Chiao CC, Mathger LM, Barbosa A, Buresch KC and Chubb, C. (In press) Cephalopod dynamic camouflage: bridging the continuum between background matching and disruptive coloration. Philosophical Transactions of the Royal Society

HONORS/AWARDS/PRIZES

National media exposure. The New York Times, Tuesday Science Section, on 19 February 2008 featured the Hanlon lab research on adaptive coloration and camouflage.
story: <http://www.nytimes.com/2008/02/19/science/19camo.html>
video: <http://video.on.nytimes.com/> (search thumbnails ... click on Cuttlefish Camouflage)
poetry: <http://digitalcuttlefish.blogspot.com/2008/02/stop-presses.html>
podcast: <http://podcasts.nytimes.com/podcasts/2008/02/15/19scienceupdate.mp3>